Energy Dissipation Studies in the South China Sea

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Award Numbers: N00014-04-1-0734, N00014-05-1-0360
http://turbulence.ocean.fsu.edu/

LONG-TERM GOALS

We are focused on understanding small-scale processes that influence the ocean's thermodynamic and dynamic properties on the sub-mesoscale (scales less than 10 km). This includes the role of turbulence in modifying the upper ocean temperature and density structure. In the South China Sea, large-amplitude, nonlinear waves force turbulence in the seasonally variable continental shelf region. New observational data is sought for use in characterizing turbulence phenomena, and for parameterizing processes in models.

OBJECTIVES

This program was focused on measuring the dissipation rate of mechanical energy on the shallow continental shelf of the South China Sea. The measurements are being used to examine the energy dynamics of small-scale wave processes in relation to tidal forcing. The measurements are the first dissipation observations from a region where extreme-amplitude, nonlinear internal waves loose their energy in shallow water.

APPROACH

The continental shelf region of the South China Sea is a complex region. Gawarkiewicz et al. (2004) present results from extensive hydrographic surveys of the northern South China Sea. They document significant modes of seasonal and interannual variability along the waters of the continental slope. Gawarkiewicz et al. (2004) identify variations in the on-shelf buoyancy forcing during winter, and also intrusions of the Kuroshio Current, as primary processes influencing water mass conditions in this region. The extent to which these seasonal and interannual variations influence the propagation and dissipation of nonlinear internal wave has not yet been established.

Orr and Mignerey (2003) present high frequency acoustic imagery showing details of the Luzon waves as they propagate up onto the continental shelf. Their imagery shows the conversion of depression waves into elevation waves occurring near the 200 m isobath. The waves were tracked by ship, and simultaneous ADCP velocity measurements were used to estimate wave energy. Orr and Mignerey report significant energy exchange between individual crests as the wave group moves toward shallower water. They find clear evidence that some wave energy is lost to turbulence, but they were unable to measure the wave energy flux and dissipation directly.

During the 2005 South China Sea pilot program, we deployed the Multiparameter Microstructure Sonde (MSS) turbulence profiling system as a component of the shallow water physical oceanography

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **Energy Dissipation Studies in the South China Sea**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida State University,Department of Oceanography,Tallahassee,FL,32306**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

survey. As such, this work was a direct collaboration with the NTU hydrography program (Joe Wang), the WHOI scanfish/mooring program (Glen Gawarkiewicz), and the NPS acoustic mooring program (Ching-Sang Chiu). The survey (Figure 1) was carried out on the *R\V Ocean Researcher 1*, during the period of April 4-21. Intensive turbulence sampling was concentrated in the period of April 15-19; corresponding to neap tide period of the local shelf tides (Figure 2). During the same period the Luzon tidal currents were still decreasing from the previous spring tide, and transbasin waves generated during the spring tide peak at Luzon were most likely influencing the continental shelf.

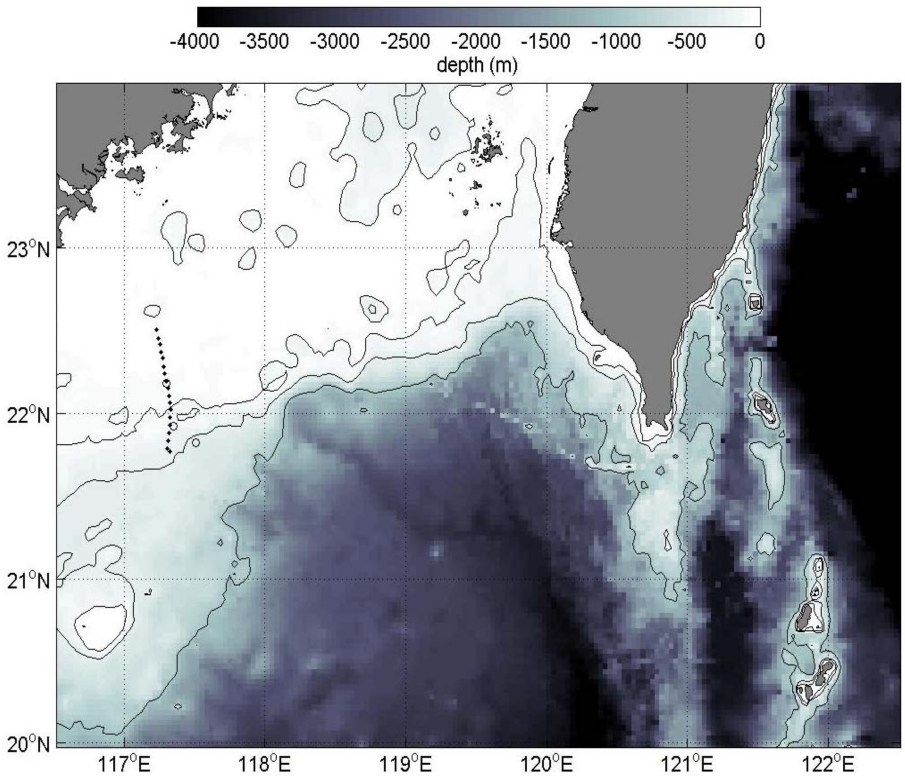

Figure 1. Map showing the region of the SCS 2005 turbulence sampling program. A primary transect runs roughly north-south from the 40-m isobath to the 300-m isobath. Timeseries occupation sites were done at the 70-m, 160-m, and 320-m isobaths.

The focus of the FSU program was the characterization of dissipative processes acting on the continental shelf of the South China Sea. Several initial ideas guided the planning for the filed program:

- Waves on the shelf would come in groups (12-hr, 24-hr) associated with Luzon forcing.
- A maximum in wave activity would occur on shelf about 3-4 days after Luzon spring-tide.
- Dissipation of waves would be maximum in shallow water, where the stratification "runs out."

However, numerous open questions about the wave processes also motivated the sample strategy. For example, how is the dissipation modulated by the spring-neap cycle? How does mesoscale variability affect the dissipation processes? What are the key physical parameters that characterize the dissipative processes?

Measurements from the MSS system provide profiles of temperature, salinity, and turbulence dissipation microstructure. Profiles on the continental shelf were bottom landed, so that data span

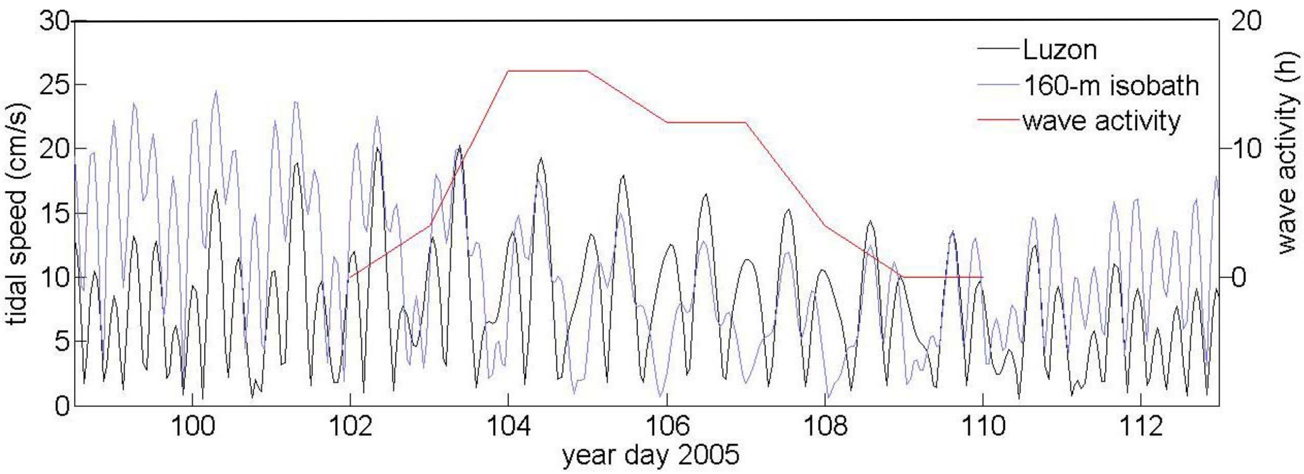

Figure 2. Zonal tidal currents at the Luzon Strait and survey region sites. The TPXO.5 model was used to compute the barotropic tidal velocity record at Luzon (21N, 121E; black line) and the 160-m isobath site in the survey region (21.84N, 117E; blue line). An assessment of ship-based acoustic imagery was done for each day during the survey, and the number of hours of strong wave activity was noted, indicated by the red line.

nearly the full depth; from $z=-5$ m to the bottom. On the continental slope, sampling was generally to $z=-200$ m, although occasional casts to the bottom were also done where depths reached 600 m. The MSS profiler system is described by Wolk et al. (2004).

RESULTS

Analysis of tidal forcing at the Luzon passage and the 160-m isobath of the continental slope survey region was performed using predictions from the TPXO.5 model. Tidal current amplitude variations at both sites are mixed-diurnal, and both sites experience a strong spring-neap cycle (Figure 2). Spring tides occur at Luzon roughly 3 days before peak tides at the continental shelf. Acoustic imagery was examined for all 10-days of the ship-based survey, and the duration of *strong* nonlinear wave activity was documented for each day. Strong waves were generally absent in the early and late days of the ship survey. Strong wave activity grew over 2 days to a maximum of 20 hours on April 14, and strong wave activity persisted over a 4-day period.

During the field program, turbulence sampling included a spatial survey, as well as timeseries occupations. The primary spatial survey examined energy dissipation levels along a transect running from roughly the 40-m to 300-m isobath (Figure 3). This survey revealed nonlinear wave activity throughout the continental shelf region, including the 40-m isobath. The strongest wave activity appears to occur in the shelf break region, between the 100-m and 300-m isobath. Turbulence levels are also largest in this region, suggesting that dissipation may contribute significantly to the evolution of Luzon waves as they propagate into shallow water.

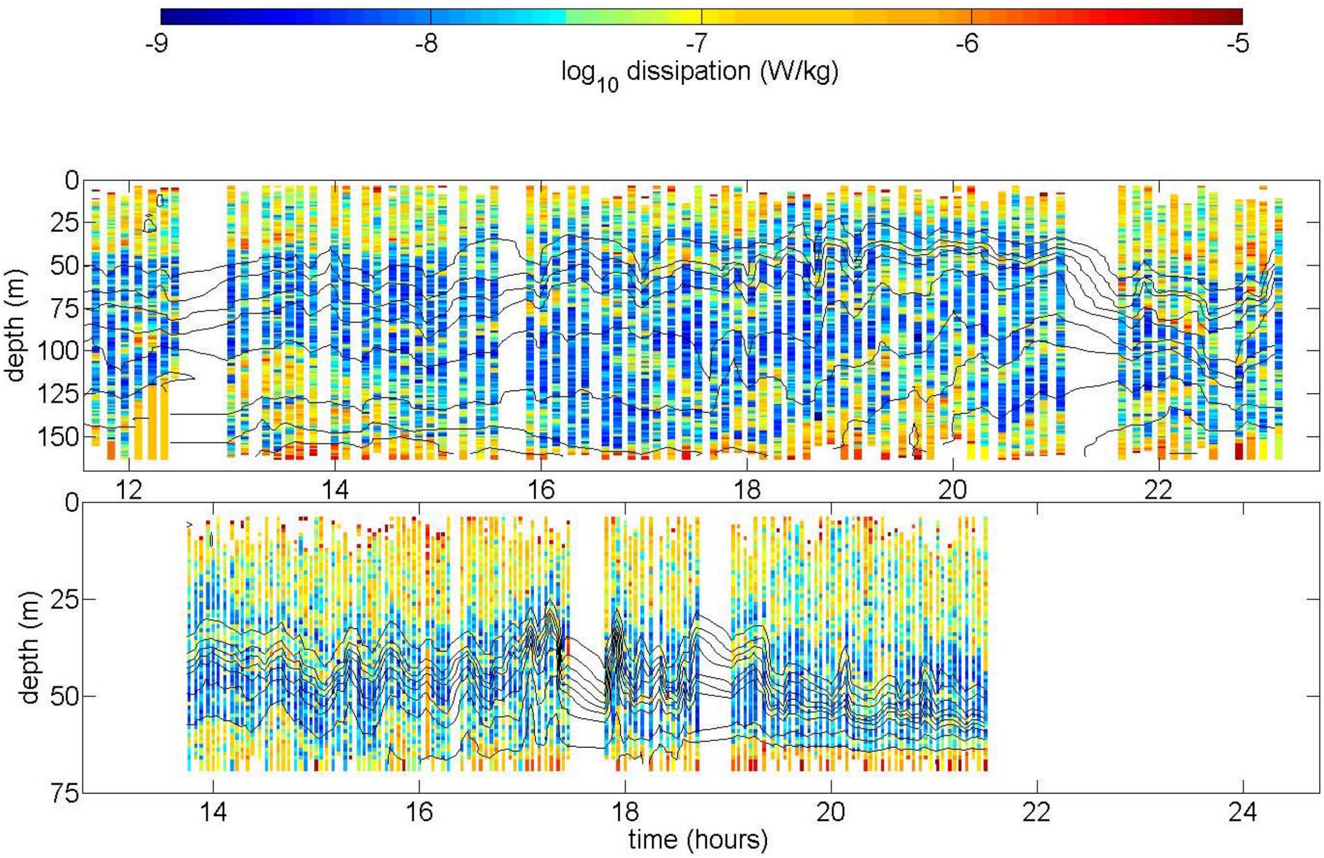

Figure 4. Time series occupation of the 70-m and 160-m isobath, showing turbulence dissipation rate data and temperature contours. High turbulence rates are apparent in the surface and bottom boundary layers, and in intermittent patches within the stratified layer. Several bursts of nonlinear waves are present in the records.

Time series occupations were done at several sites in the survey region. Primary occupations were done at the 70-m, 160-m, and 320-m isobaths. These were intended as 12-hr timeseries, though the 70-m isobath occupation was reduced to 8 hrs when fishing activity jeopardized the safety of the instrumentation. The 70-m timeseries shows several periods of strong nonlinear wave activity (Figure 4). Turbulence levels remain strong between periods of strong waves, particularly in the bottom boundary layer. While bottom boundary layer turbulence is sustained by the barotropic tidal current, intermittent turbulence in the stratified layer occurs during the passage of waves.

In all, over 350 profiles were collected during the 2-week program. Thus, the measurements span a spring-neap cycle of the local shelf tide. In addition, most profiles were to full depth, with

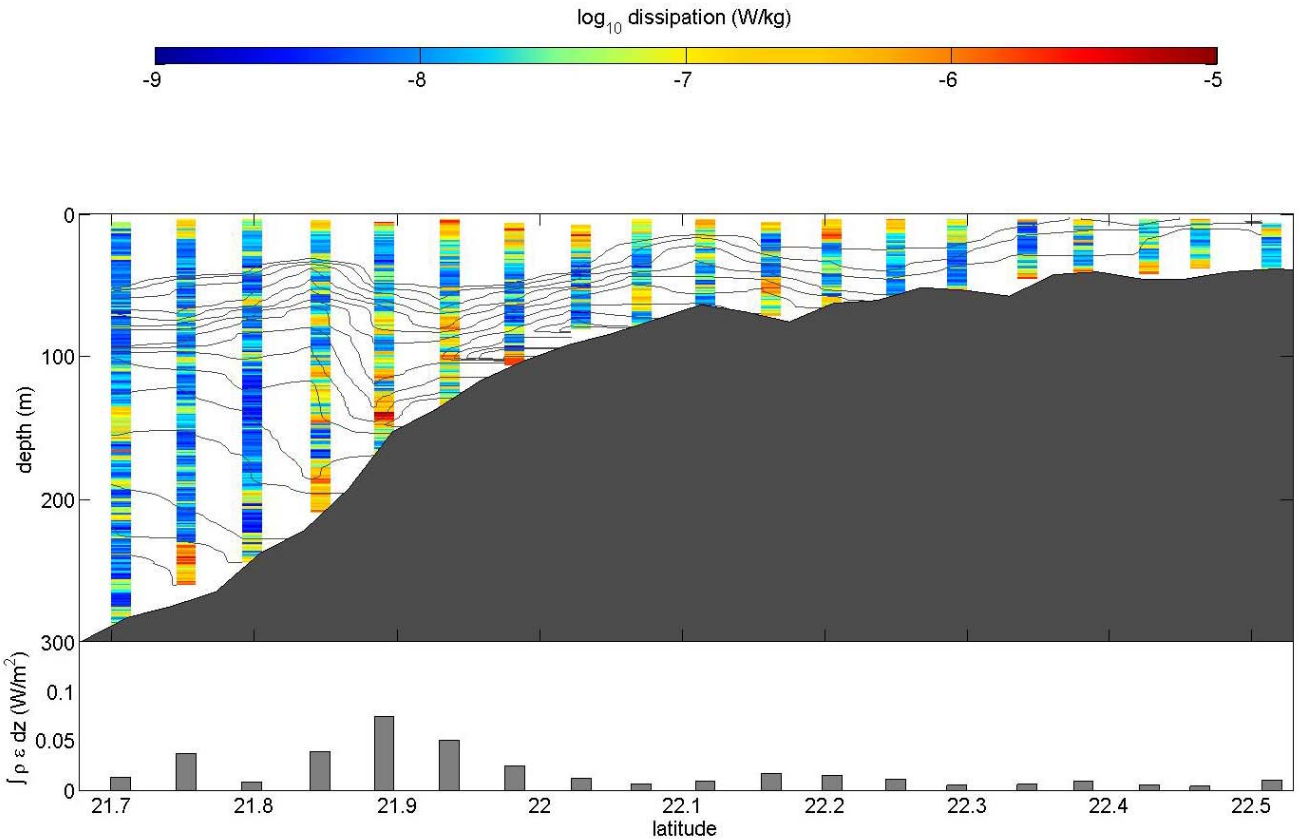

Figure 3. Section of turbulence dissipation across the continental shelf of the survey region. Contours show the fluctuations of the temperature field along the transect. The bottom panel shows vertically integrated dissipation for each profile.

measurements resolved into the bottom boundary layer. A brief preliminary summary of the important findings is listed here:

- Wave activity on the continental shelf was persistent throughout the observation period.
- Wave groups did not arrive in clear 6-, 12-, or 24-hr intervals.
- Waves were nonlinear, but generally not soliton-like.
- The stratification was continuous between the surface and bottom boundary layers, and not describable as a two-layer system.
- Dissipation levels were largest at shelf break region (100-m to 300-m isobath).

IMPACT/APPLICATIONS

The new data collected in the 2005 observational program provides the first picture of the spatial and temporal signals of nonlinear internal wave finestructure on the continental shelf of the South China Sea. These measurements, in conjunction with model simulations and the efforts of other groups, will establish the basis for an internal-wave climatology of this important WestPac region.

RELATED PROJECTS

Our work significantly leverages on the ONR/YIP supported modeling effort of Harper Simmons (UAF-IARC) entitled "A study of internal wave generation, evolution and propagation in a global baroclinic ocean model." That study involves an intensive effort on the part of the Co-PI to improve the model physics and computational capabilities in the context of global internal wave modeling. It also contains a regional modeling component that has already resulted in regional modeling capability with open boundary conditions and boundary forcing with a prescribed barotropic tide. It is expected that for a modest effort, the currently proposed work can produce significant returns from adjustments to the existing model configuration. An extremely high resolution Western Pacific model with a South China Sea focus is the expected end product. The proposed study, combining observations and numerical modeling, will hopefully result in improvements to our physical understanding of the life cycle of internal waves. Additionally, it is hoped that improved physical understanding and regional model validation will strengthen not only our already funded global study but also global-scale modeling in general.

The PI has also worked on a study of the global distribution of mixing rates (St. Laurent and Simmons 2006), mixing driven by turbulence production of marine animals (Dewar et al. 2006), and a review article on bottom boundary layer turbulence (Lueck and St. Laurent 2006). These studies are part of the general effort to examine small-scale processes in a variety of dynamical regimes.

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